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RESEARCH ON ELEMENTAL ABUNDANCES IN METEORITIC AND TERRESTRIAL MATTER

SUMMARY PROGRESS REPORT

September 1, 1963, through August 31, 1964

Contract NASw-843
National Aeronautics and Space Administration

Work done by:

R. A. Schmitt
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Report written by:

R. A. Schmitt

August 31, 1964

INTRODUCTION

This summary progress report of the third year of research on elemental abundances under National Aeronautics and Space Administration Contracts NASr-75, NASw-579, and NASw-843, covers the contract period from September 1, 1963, through August 31, 1964.

During the quarter from June 1 through August 31, 1964, abundances of seven elements--Na, Sc, Cr, Mn, Fe, Co, and Cu--were determined by the technique of instrumental neutron activation analysis (INAA) in 25 individual chondrules separated from the Type II carbonaceous chondrite Al Rais. Abundances of Sc, Cr, Fe, and Co were also measured in 6 individual Karoonda chondrules.

During the past contract year, emphasis has been directed toward abundance determinations of the seven elements Na, Sc, Cr, Mn, Fe, Co, and Cu in over 80 meteorites, 218 individual chondrules (separated from 11 chondritic meteorites), and a few terrestrial specimens via INAA. Abundances of these seven elements could be easily determined in these "battleship-type" experiments because convenient radioisotopes (2.56-hr to 5.3-yr half lives) of these elements are generated in meteoritic stony matter by thermal-neutron activation and are measured by gamma-ray scintillation spectrometry.

An extensive manuscript entitled "Abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in 218 Individual Meteoritic Chondrules via Activation Analysis, I" by R. A. Schmitt, R. H. Smith, and G. G. Goles has been in preparation during the last quarter for submittal to Geochimica et Cosmochimica Acta. All the measurements on Al Rais and Karoonda chondrules have been included in this manuscript, which is summarized in the first abstract in the next section.

Also during this quarter, a detailed manuscript covering the research over the past year on elemental abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in more than 80 meteorites has been in preparation by Schmitt, Goles, and Smith.

In collaboration with E. Bingham and A. A. Chodos, zirconium abundances have been determined in more than 30 meteorites and 4 terrestrial specimens via emission spectrographic techniques. A manuscript on this work has been accepted for publication in Geochimica et Cosmochimica Acta (1964), and the abstract has been included in the next section.

In order to calculate the more than 2000 elemental abundances (7 elements in more than 300 meteoritic chondrites and chondrules), a computer program (for the IBM 7044) for calculating abundances using the peak-area method has been devised during the past year. A description of the program will be submitted to Science (1964) for publication, and the entire computer language will appear in a forthcoming General Atomic report in 1964. The Science abstract is given in the next section.

Four oral presentations based on the elemental abundance data obtained this past year were given at the following meetings: Second National Meeting of the Society for Applied Spectroscopy ("Abundances of Na, Sc, Mn, Cr, Fe, and Co in Stony Meteorites via Instrumental Neutron Activation Analysis," by Schmitt and Goles), Meeting of the American Association for the Advancement of Science ("Instrumental Neutron Activation Analysis of Chondritic Meteorites and Some Geochemical Implications," by Goles and Schmitt), Symposium on Elemental Abundances at U. C. L. A. ("Abundances of Na, Sc, Cr, Mn, Fe, Co, and Cu in Chondritic Meteorites and Individual Chondrules," by Goles, Schmitt, and Smith), and Chemistry and Physics of Space Gordon Research Conference ("Elemental Abundances in Chondrites and Chondrules," by Schmitt, Goles, and Smith). Abstracts of the first two papers have been appended in the next section.

ABSTRACTS

The abundance determinations resulting from work during the current contract year have been published in various technical journals or are in preparation. In addition, papers were presented at four conferences. Abstracts of two of these papers are given below.

ABUNDANCES OF Na, Sc, Cr, Mn, Fe, Co AND Cu IN 218 INDIVIDUAL METEORITIC CHONDRULES VIA ACTIVATION ANALYSIS, I*

R. A. Schmitt, R. H. Smith and G. G. Goles†

Instrumental neutron activation analysis (INAA) has yielded the abundances of the seven elements Na, Sc, Cr, Mn, Fe, Co, and Cu in 218 individual chondrules and 6 olivine crystals separated from 11 chondritic meteorites. For comparison, abundances of these seven elements were also determined by INAA in these and other whole chondrites. The technique was thermal-neutron activation followed by gamma-ray scintillation spectrometry. After a decay of a few hours following 1 to 2 hr of neutron irradiation, the prominent gamma rays from chondrules and/or chondrites are due to Na^{24}, Mn^{56}, and Cu^{64}; after a decay of two weeks, the principal gamma rays are due to Sc^{46}, Cr^{51}, Fe^{59}, and Co^{60}. Abundances have been calculated by the peak-area method (Compton continuum subtracted) for the prominent gamma rays and also by use of an IBM 7044 computer programmed for the peak-area method.

Our principal observations are:

Na--Average abundances in Type II chondrules (e.g., chondrules separated from Type II carbonaceous chondrites) are ~800 ppm, less by a factor of ~9 than the abundances of Na in ordinary chondrules (separated from ordinary chondrites). Assuming 17% Si in the chondrules, the ratio of ~6000 Na/10^6 Si atoms is in good agreement with the recent Na solar value (Aller, 1962) of 9000. Na abundances for Type III chondrules (separated from Type III chondrites or Ornansites) are intermediate between those for Type II and for ordinary chondrules.

Sc--Average abundances are rather similar in all chondrules, and ~30% more Sc resides in chondrules as compared with the whole chondrites.

Cr--Average abundances in Type II chondrules are ~50% greater than in ordinary chondrules. An approximate ratio of 14,000 Cr/10^6 Si atoms in Type II chondrules (compared with 12,000 Cr/10^6 Si atoms in

*Submitted for publication to Geochimica et Cosmochimica Acta, October, 1964.

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Type II carbonaceous chondrites) is above the Cr solar value of 7300 (Goldberg, et al., 1960). Cr abundances in Type III chondrules are intermediate between those in Type II and in ordinary chondrules.

Mn--Average abundances in Type II chondrules at ~1500 ppm are about a factor of 2 less than in ordinary chondrules, with abundances in Type III chondrules intermediate and scattered. Ordinary chondrules have exceptionally low mean deviations (~ ±5%) for Mn abundances in sets from individual meteorites. We observed large mean deviations (up to 35%) in Type II and Type III chondrules. A ratio of ~4000 Mn/10^6 Si atoms in Type II chondrules compares moderately well with the 2500 Mn/10^6 Si atom ratio in the sun and the corresponding value of 7000 in Type II carbonaceous chondrites.

Fe--Fe abundances of ~6.8% have been found in Type II chondrules and of ~9.5% in ordinary chondrules, with variable amounts in Type III chondrules. A mass effect has been observed for some chondrule groups; i.e., heavier chondrules contain more total Fe. Mean deviations of Fe abundances in Type II chondrules vary from 59% to 74%. They are considerably lower (15% to 31%) for ordinary chondrules. Type II chondrules have ~200,000 Fe/10^6 Si atoms compared with the solar ratio of 123,000 Fe/10^6 Si atoms. The corresponding average ratio in ordinary chondrites is 700,000 Fe/10^6 Si atoms.

Co--Average abundances of Co at ~260 ppm in Type II chondrules are ~5 times greater than in ordinary chondrules. High Co contents in Type III chondrules seem to be correlated with the magnetic character of certain chondrules. Fe, Co, and Cu may be weakly covariant in Type III chondrules. Type II chondrules have 700 Co/10^6 Si atoms compared with 1400 for the solar value and 2000 for the Type II carbonaceous chondrites.

Cu--Average abundances (at 70 ppm) of Cu are similar for all chondrule categories, and all have large mean deviations. An atomic ratio of 200 Cu/10^6 Si may be compared with the recent solar Cu value of 100 (Aller, 1962) and a value of 400 for the Type II carbonaceous chondrites.

Although the abundances of these seven elements in chondrules from Type II carbonaceous chondrites agree approximately with solar abundance values, the concentrations of many other chemical elements with diverse chemical properties must be ascertained in these chondrules before they can be regarded (Wood, 1963) as approximating condensations from the primordial solar nebular matter.

RARE EARTH, YTTRIUM AND SCANDIUM ABUNDANCES IN METEORITIC AND TERRESTRIAL MATTER, II*

R. A. Schmitt, R. H. Smith and D. A. Olehy

Abundances and selected isotopic ratios of the 14 rare-earth elements (REE), yttrium, and scandium have been determined by neutron-activation analysis in 13 meteorites and 2 terrestrial specimens: 3 carbonaceous, 2 hypersthenic, and 1 bronzitic (troilite phase) chondrite; 2 calcium-rich and 2 nakhlitic achondrites; 1 mesosiderite; 2 pallasites; an Australian eclogite; and a Columbia Plateau basalt. This research is a continuation of recent REE work by Schmitt, _et al_. (1963a). Absolute abundances of the REE and Sc in 2 Type I carbonaceous chondrites are about 33 percent less than that of the Type II. Atomic ratios of Y/10^6 Si in carbonaceous chondrites remain approximately constant at 4. 7 (Type I), 4. 1 (Type II), and 4. 8 (Type III), and ratios of the REE (La is representative) yielded La/10^6 Si at 0. 36 (Type I), 0. 53 (Type II), and 0. 51 (Type III). The REE, Y, and Sc contents in the troilite phase of a chondrite are 0. 3 of the content in the entire chondritic matrix. REE and Y abundances in Ca-rich achondrites and nakhlites are ~10 and ~5 times larger, respectively, than are found in ordinary chondrites. No fractionation of the REE and Y distribution was observed in Ca-rich achondrites compared to chondritic REE and Y; fractionation in nakhlites is similar to that in terrestrial basalts. Fractionation of the REE and Y (Eu is enriched) in the mesosiderite Veramin and in two pallasites (Eu depleted in one pallasite) has been found. The observed fractionation of the REE and Y in Australian eclogite was opposite to fractionation in African eclogite, and fractionation in Columbia Plateau basalt was similar to that in Kilauea basalt.

*_Geochimica et Cosmochimica Acta_, Vol. 28, No. 1, pp. 67-86, 1964.

CADMIUM ABUNDANCES IN METEORITIC AND TERRESTRIAL MATTER*

R. A. Schmitt, R. H. Smith and D. A. Olehy

Abundances of cadmium have been determined by neutron-activation analysis in 31 meteorites with the following results: 0.52 to 1.16 ppm in five carbonaceous chondrites; 0.015 to 0.12 ppm in six ordinary bronzitic and hypersthenic chondrites; 0.042 to 3.3 ppm in three enstatitic chondrites; 0.022 and 0.065 ppm in two eucritic achondrites; 0.18 and 1.79 ppm in two nakhlitic achondrites; ≤ 0.010 and 0.33 ppm in two calcium-poor achondrites; < 0.004 and 0.056 ppm in two mesosiderites; 0.13 and 0.33 ppm in two pallasites; and 0.0085 to 0.056 ppm in seven iron meteorites. An atomic abundance of Cd/10^6 Si atoms of 1.8 ± 0.6 is calculated for five carbonaceous chondrites, which agrees well with the solar value of 1.5 given by Aller (1962). Cadmium abundances in two terrestrial basalts were 0.33 and 0.5 ppm and 0.026 and 0.24 ppm in two deep-seated eclogites. Abundances of cadmium and other chalcophilic elements are discussed in terms of chondritic parent models. Low fractional abundances in the earth's crust of the chalcophilic elements cadmium (0.0085), zinc (0.0014), bismuth (0.0045), and thallium (0.33), corroborate the conclusions reached by Gast (1960), that either the earth's original composition was not chondritic-like, or that elements like the alkalis (and the chalcophilics) reside below the crust.

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*Geochimica et Cosmochimica Acta, Vol. 27, No. 1, pp. 1077 to 1088, 1963.

ZIRCONIUM ABUNDANCES IN METEORITES AND IMPLICATIONS TO NUCLEOSYNTHESIS*

R. A. Schmitt, E. Bingham,† and A. A. Chodos†

The atomic abundance of Zr has been established at 16 ±5 Zr atoms/10^6 Si atoms in seventeen ordinary chondrites, which agrees well with Aller's (1962) solar value of 14 Zr atoms/10^6 Si atoms. Apparently, fractionation of Zr has occurred within the chondritic family, since 22 ±3 Zr atoms/10^6 Si atoms were observed in seven Type II and Type III carbonaceous chondrites. Zr has been enriched in four Ca-rich achondrites by a factor of five, which is consistent with other trace-element enrichments. Zr may be depleted in Ca-poor achondrites and pallasitic olivines. The low Zr abundance in chondrites, coupled with Rb, Sr, Y, and Mo chondritic abundances, indicates 50 percent enhancement of the odd-A mass distribution at A = 89 due to the 50-neutron-shell closure. Abundance values of Zr and other nearby elements indicate that Fe^{56} seed nuclei were exposed to different neutron fluxes. The atomic ratio Zr/Hf of 100 in meteorites compared with 106 in the terrestrial crust indicates no serious fractionation between these two very similar chemical elements.

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*Accepted for publication in Geochimica et Cosmochimica Acta, June 1964.

† California Institute of Technology, Department of Geological Sciences, Pasadena, California.

GAMMA-RAY SPECTRA ANALYZED BY COMPUTER PROGRAM USING PEAK AREA METHOD*

S. C. Choy and R. A. Schmitt

A computer program has been devised for use in gamma-ray spectroscopic analysis which yields elemental concentrations in parts per million (ppm) and their standard deviations due to counting statistics from the observed peak areas (Compton continuum subtracted). In the computer analysis, radioisotopes may be identified by ratios of the peak areas of two or more gamma-rays.

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*To be submitted to Science, 1964.

ABUNDANCES OF Na, Sc, Mn, Cr, Fe, AND Co IN STONY METEORITES VIA INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS*

R. A. Schmitt and G. G. Goles†

Abundances of Na, Sc, Mn, Cr, Fe, and Co have been determined by instrumental neutron activation analysis in over two hundred stony meteorites, i. e., in 170 chondrites and achondrites, ~10 mesosiderites, and ~20 pallasites, primarily from the Nininger Meteorite Collection. Analyses for Na and Mn were made in groupings of 35 samples. About 35 meteoritic specimens of 0.1 to 0.5 g each, plus Na, Sc, Mn, Cr, Fe, and Co standards, were irradiated simultaneously in the TRIGA reactor for 5 min at 2×10^{11} neutrons cm^{-2} sec^{-1}. After decay of short-lived radioactivities, gamma-ray spectra were taken of the specimens and appropriate standards via scintillation spectrometers (3 × 3 NaI well and solid crystals in 4 in. lead shields) coupled to 256-channel or 400-channel analyzers. Distinct peaks of 2.56-hr Mn^{56} (0.85 Mev) and 15-hr Na^{24} (1.37 and 2.75 Mev) yielded the Mn and Na abundances. After a reirradiation of the 36 specimens with Sc, Cr, Fe, and Co standards for 30 min at 2×10^{12} neutrons cm^{-2} sec^{-1} in the TRIGA reactor and after a decay of two weeks, distinct gamma-ray spectra of 85-d Sc^{46} (2.01 Mev sum peak), 27.5-d Cr^{51} (0.32 Mev), 45-d Fe^{59} (0.19 Mev) and 5.2-y Co^{60} (2.50 Mev sum peak) for the specimens and standards yielded the Sc, Cr, Fe, and Co abundances. Results and their interpretation will be discussed.

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*Presented at the Second National Meeting of the Society for Applied Spectroscopy, San Diego, October 14-18, 1963.

† University of California, San Diego, California.

INSTRUMENTAL NEUTRON ACTIVATION ANALYSES OF CHONDRITIC METEORITES AND SOME GEOCHEMICAL IMPLICATIONS*

G. G. Goles† and R. A. Schmitt

Analyses for a group of elements including Na, Mn, and Co in chondrites have been made by instrumental neutron activation techniques. Data on Na compare well with the analyses of Edwards and Urey (1955) and in general indicate a smaller variance among chondrites of a given group than has been found by other methods of analysis. Significant differences between the Na abundances of chondritic groups exist. Mn abundances from whole-rock-type analyses show considerable variations, which are weakly correlated with chondritic groupings, but Mn in individual chondrules is remarkably constant, both among those from a single chondrite and among those from different chondrites. Comparisons of Co abundances with data on Fe in the metallic phase corroborate the conclusions of Urey and Craig (1953) and support their modification of Prior's law.

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*An abstract of this paper was presented at the Cleveland Meeting of the American Association for the Advancement of Science, December 28, 1963.

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